5. DOSE

5.1 SUMMARY

Potential impacts on human health from radionuclides released by PORTS operations are calculated based on environmental monitoring data. This impact, called a dose, can be caused by radionuclides released to air and/or water, or radiation emanating directly from buildings or other objects at PORTS. The U.S. EPA sets a 10 millirem (mrem)/year limit for dose from radionuclides released to the air and the DOE sets a 100 mrem/year limit for dose from radionuclides from all potential pathways (air, water, and direct radiation). A person living in southern Ohio receives a dose of approximately 300 mrem/year from natural sources of radiation. This chapter includes radiological dose calculations for the dose to the public from radionuclides released to the air and surface water, and from direct radiation. The maximum dose a member of the public could receive from radiation released by PORTS in 1999 is 0.92 mrem, based on a maximum dose of 0.28 mrem from airborne radionuclides, 0.053 mrem from radionuclides released to the Scioto River, and 0.59 mrem from direct radiation from the PORTS depleted uranium cylinder storage yards. Table 5.1 summarizes this dose information.

Table 5.1. Summary of potential doses to the public from radiation released by PORTS operations in 1999

Source of dose	Dose (mrem)
Airborne radionuclides	0.28
Radionuclides released to the Scioto River	0.053
Direct radiation from depleted uranium cylinder storage yards	0.59
Total	0.92

5.2 INTRODUCTION

As discussed in this chapter, dose is a measure of the potential biological damage that could be caused by exposure to and subsequent absorption of radiation to the body. Because there are many natural sources of radiation, a person living in the Portsmouth area receives a dose of approximately 300 mrems/year from sources of natural radiation. Appendix A provides additional information on radiation and dose.

Releases of radionuclides such as uranium from PORTS activities can cause a dose to a member of the public in addition to the dose received from natural sources of radiation. PORTS activities that release radionuclides are regulated by the U.S. EPA and DOE. Airborne releases of radionuclides from DOE facilities are regulated by the U.S. EPA under the Clean Air Act and the National Emission Standards for Hazardous Air Pollutants. These regulations set an annual dose limit of 10 mrem/year to any member of the public as a result of airborne radiological releases. Airborne radionuclide discharges may also be regulated, along with all other atmospheric pollutants, under the State of Ohio Permit to Operate requirements for sources of air emissions.

DOE also regulates radionuclide emissions to all environmental media through DOE Orders 5400.1, *General Environmental Protection Program,* and 5400.5, *Radiation Protection of the Public and the Environment.* DOE Order 5400.5 sets an annual dose limit of 100 mrem/year to any member of the public from all radionuclide releases from a facility, unlike the National Emission Standards for Hazardous Air Pollutants, which apply to only airborne radiological releases.

Small quantities of radionuclides were released to the environment from DOE/PORTS operations during 1999. This chapter describes the methods used to estimate the potential doses that could result from radionuclides released from PORTS operations.

5.3 RADIOLOGICAL DOSE CALCULATION

Exposure to radioactive materials can occur from releases to the atmosphere, surface water, or groundwater. In addition, a dose could be received through direct external irradiation by radiation emanating from buildings and other objects located within PORTS boundaries. Doses are estimated for all potentially significant exposure pathways relevant to the exposure modes just described. For 1999, doses are estimated for exposure to atmospheric releases, releases to surface water, and direct radiation. Exposure to the radionuclides from groundwater is not included because contaminated groundwater at PORTS is contained on site and is not a source of drinking water.

In addition, DOE Order 5400.5 sets an absorbed dose rate of 1 rad per day to native aquatic organisms. This chapter contains the dose calculations required to demonstrate compliance with this requirement.

DOE/PORTS workers and visitors who may be exposed to radiation are also monitored. These results are discussed at the end of this chapter.

5.3.1 Terminology

Most consequences associated with radionuclides released to the environment are caused by interactions between human tissue and various types of radiation emitted by the radionuclides. These interactions involve the transfer of energy from radiation to tissue, possibly resulting in tissue damage. Radiation may come from radionuclides outside the body (in or on environmental media or objects) or from radionuclides deposited inside the body (by inhalation, ingestion, and, in a few cases, absorption through the skin). Exposures to radiation from radionuclides outside the body are called external exposures and exposures to radiation from radionuclides inside the body are called internal exposures. This distinction is important because external exposure occurs only as long as a person is near the external radionuclide; simply leaving the area of the source will stop the exposure. Internal exposure continues as long as the radionuclide remains inside the body.

The three natural uranium isotopes (uranium-234, uranium-235, and uranium-238) and technetium-99 are the most significant radionuclides when calculating the radiation dose received by the public around PORTS. Other radioactive isotopes are also part of the radioactive dose received from PORTS operations.

A number of specialized units have been defined for characterizing exposures to ionizing radiation. Because the damage associated with such exposures results primarily from the deposition of radiant energy in tissue, the units are defined in terms of the amount of incident radiant energy absorbed by tissue and in terms of the biological consequences of the absorbed energy. These units include the following:

- *Absorbed dose* – a physical quantity that defines the amount of incident radiant energy absorbed per unit mass of an irradiated material; its unit of measure is the rad. The absorbed dose depends on the type and energy of the incident radiation and on the atomic number of the absorbing material.

- *Dose equivalent* – a quantity that expresses the biological effectiveness of an absorbed dose in a specified human organ or tissue; its unit of measure is the rem. The dose equivalent is numerically equal to the absorbed dose multiplied by modifying factors that relate the absorbed dose to biological effects.

- *Effective dose equivalent* – a weighted sum of dose equivalents to specified organs that can be used to estimate health-effect risk to exposed persons. In this report, the term "effective dose equivalent" is often shortened to "dose."

- *Committed (effective) dose equivalent* – the total (effective) dose equivalent that will be received over a specified time period (in this document, calculations are based on a 50-year period) because of radionuclides taken into the body during the current year.

- *Collective dose equivalent* – the sum of committed (effective) dose equivalents to all individuals in an exposed population. The unit of measure is the person-rem. The collective dose is also frequently called the "population dose."

- *Total effective dose equivalent* – the sum of the effective dose equivalent for external exposures and the committed (effective) dose equivalent for internal exposure.

5.3.2 Dose Calculation for Atmospheric Releases

A dose calculation for atmospheric, or airborne, radionuclides is required by the U.S. EPA under the program called the National Emission Standards for Hazardous Air Pollutants. The effect of radionuclides released to the atmosphere by DOE/PORTS during 1999 was characterized by calculating effective dose equivalents to the maximally exposed person (the individual who resides at the most exposed point near the plant) and to the entire population (approximately 600,000 residents) within 50 miles of the plant. Dose calculations were made using a computer program called CAP-88 (Beres 1990), which was developed under sponsorship of the U.S. EPA for use in demonstrating compliance with the National Emission Standards for Hazardous Air Pollutants for radionuclides. The program uses a model to calculate concentrations of radionuclides in the air and on the ground and uses *Nuclear Regulatory Commission Regulatory Guide* 1.109 food-chain models to calculate radionuclide concentrations in foodstuffs (e.g., vegetables, meat, and milk) and subsequent intakes by individuals. The program also uses meteorological data collected at PORTS such as wind direction, wind speed, atmospheric stability, rainfall, and average air temperature.

Radionuclide release data were modeled for two DOE/PORTS permitted sources: the X-326 L-cage Glove Box and the X-744 Glove Box. The dose calculations assumed that each person remained unprotected, resided at home (actually outside the house) during the entire year, and obtained food according to the rural pattern defined in the National Emission Standards for Hazardous Air Pollutants background documents. This pattern specifies that 70% of the vegetables and produce, 44% of the meat, and 40% of the milk consumed by each person are produced in the local area (e.g., in a home garden). The remaining portion of each food is assumed to be produced within 50 miles of DOE/PORTS. These assumptions most likely result in an overestimate of the dose received by a member of the public, since it is unlikely that a person spends the entire year outside at home and consumes food from the local area as described above.

The maximum potential dose to an off-site individual from radiological releases from DOE air emission sources at PORTS in 1999 was 0.00048 mrem/year. USEC also completes the dose calculations described above for the air emission sources leased to USEC (e.g., the uranium enrichment facilities and other sources). USEC calculated the maximum potential dose to an off-site individual in 1999 to be 0.28 mrem/year. The combined dose from USEC and DOE sources is well below the 10-mrem/year limit applicable to PORTS and the approximate 300-mrem/year dose that the average individual in the United States receives from natural sources of radiation.

The collective dose equivalent to the entire population within 50 miles of PORTS was 1.0 person-rem/year, based on USEC calculations of 1.0 person-rem/year from USEC sources and 0.00077 person-rem/year from DOE sources. The collective dose equivalent to the nearest community, Piketon, was calculated to be 0.15 person-rem/year, based on USEC calculations of 0.15 person-rem/year from USEC sources and 0.00014 person-rem/year from DOE sources.

5.3.3 Dose Calculation for Releases to Surface Water

Radionuclides are measured at each of the DOE and USEC NPDES outfalls. Water from these outfalls is either directly discharged to the Scioto River or eventually flows into the Scioto River from the Little Beaver Creek, Big Run Creek, or unnamed tributaries to these water bodies. A hypothetical dose to a member of the public was calculated using the measured radiological discharges and the average annual flow rate of the Scioto River.

Total uranium, americium-241, neptunium-237, plutonium-238, plutonium-239/240, technetium-99 and thorium-230 (selected outfalls) were measured in the water discharged from the DOE or USEC outfalls. Total uranium was assumed to be 94% uranium-235, 5.2% uranium-238, and 0.8% uranium-234. The maximum individual dose was calculated using the above mentioned measured radionuclide discharges from the plant outfalls and the average annual flow rate of the Scioto River. All discharge radioactivity levels were expressed in activity per year (Ci/yr) and used along with the average river flow to calculate radioactivity per volume.

The dose calculations were derived from the procedures developed for a similar DOE facility: *LADTAPXL: An Improved Electronic Spreadsheet Version of LADTAP II* (Hamby 1991). Environmental pathways considered were ingestion of water, ingestion of fish, swimming, boating, and shoreline activities. The assumption was made that a person eats 21 kg (46 lb) of fish caught in the Scioto River, drinks 730 L (190 gal) of river water, swims for 27 hours, boats for 105 hours, and occupies the shoreline for 69 hours during the year. Based on the calculations across all isotopes found in the outfalls, this individual could receive an annual dose of about 0.053 mrem. This is a very conservative exposure scenario because the Scioto River is not used for drinking water downstream of PORTS (about 90 percent of the hypothetical dose from liquid effluents is from drinking water).

5.3.4 Radiological Dose Calculation for Direct Radiation

The DOE/PORTS Radiological Protection Organization monitors direct radiation levels in active DOE/PORTS facilities on a continual basis. This radiation monitoring assists in determining the radiation levels that workers are exposed to and in identifying changes in radiation levels. These measurements provide (1) information for worker protection, (2) a means to trend radiological exposure data for specified facilities, and (3) a means to estimate potential public exposure to radiation from DOE/PORTS activities.

Thermoluminescent dosimeters (TLDs) are used to measure beta, gamma, and neutron radiation. The TLD consists of four crystals that store radiation as potential energy. When the TLD crystals are heated, this stored energy is released as light. This light is quantifiable and correlates directly to the amount of ionizing radiation to which the TLD was exposed. The TLD can differentiate exposure to beta, gamma, and neutron radiation as well as shallow and deep radiation. Shallow radiation penetrates only the outer portion of the skin. Deep radiation penetrates the entire body (similar to an x-ray).

Five major DOE/PORTS facilities are monitored for direct radiation exposure levels: the X-7725 Waste Storage Facility, X-326 Process Building, X-345 SNM Storage Building, X-744G Bulk Storage Building, and the X-745C and X-745E Depleted Uranium Cylinder Storage Yards.

None of these facilities are readily accessible to the public; however, Perimeter Road passes close to the edge of the cylinder yards. Therefore, data from direct radiation monitoring at the cylinder yards are used to assess potential exposure to the public from passing traffic on Perimeter Road.

The radiological exposure data provided from the TLDs at each facility are based on exposure to ionizing radiation for an entire year (i.e., 24 hours/day, 7 days/week, 52 weeks/year - 8,736 hours/year). The radiological exposure to members of the general public is estimated as the time that a person drives on Perimeter Road past the cylinder yards. Public traffic is not allowed to stop in this area, and past tests provide the estimate that a car traveling slightly under the posted speed limit passes by the cylinder yards in 20 to 30 seconds. Potential public exposure to radiation from the cylinder yards is calculated as follows:

Assumptions:

- A person driving to and from work (2 exposures/day) is the most conservative plausible scenario.
- The driver will pass by the cylinder yards within 1 minute.

Calculation:

1. Add the deep and shallow dose rates to get a combined dose for the year.

2. Subtract natural background radiation – 78 mrem/year. Natural background radiation consists of 50 mrem/year cosmic radiation and 28 mrem/year terrestrial radiation (see Appendix A).

3. Divide this dose measurement by 8736 hours to determine the exposure per hour.

4. Multiple this exposure by 8.7 hours/year (1 minute/trip x 2 trips/day x 5 work-days/week x 52 weeks/year).

The average deep dose and shallow dose reported in Table 5.2 represent the gross exposure levels at each facility. These levels include ionizing radiation from PORTS activities in those areas and natural background radiation (i.e., terrestrial and cosmic radiation). The final column provides the potential dose to the public from each area.

Table 5.2. Direct radiation doses at DOE/PORTS facilities – 1999

Facility	Average deep dose (mrem/year) continuous exposure (8736 hours)	Average shallow dose (mrem/year) continuous exposure (8736 hours)	Estimated public dose (mrem/year) 8.7 hours exposure
X-7725	20	43	NA[a]
X-326	3	16	NA[a]
X-345	5	11	NA[a]
X-744G	103	85	NA[a]
X-745C	161	134	0.22
X-745E	242	203	0.37

[a] Not applicable - no public exposure to radiation from these buildings.

Based on the assumptions and calculations provided, exposure to the public from radiation from the cylinder yards is approximately 0.59 mrem/year. The average yearly dose to a person in the United States is approximately 366 mrem: 300 mrem from natural radiation sources and 66 mrem from manmade radiation sources (see Appendix A). The potential estimated dose from the cylinder yards to a member of the public is less than 0.2 percent of the average yearly radiation exposure for a person in the United States.

5.3.5 Radiological Dose Calculation for Aquatic Biota

DOE Order 5400.5 sets an absorbed dose rate of 1 rad/day to native aquatic organisms. To demonstrate compliance with this limit, absorbed dose rates to crustacea, mollusks, and fish were calculated using the CRITR2 computer code (Baker and Soldat 1992) and average annual radionuclide concentrations in the Scioto River. The CRITR2 computer model estimates dose rates from internally deposited radionuclides, from immersion in water, and from sediment irradiation.

Modeling results indicate that the aquatic biota in the Scioto River did not receive an absorbed dose of more than 1 rad/day in 1999. Internal and external dose rates were 0.0000032 rad/day to fish, and 0.000006 rad/day to crustacea and mollusks.

5.3.6 Radiological Dose Results for DOE/PORTS Workers and Visitors

The Radiation Exposure Information Reporting System report is an electronic file created annually to comply with DOE Order 231.1. This report contains exposure results for all monitored individuals at DOE/PORTS, including visitors, with a positive exposure during the previous calendar year. The 1999 Radiation Exposure Information Reporting System report indicated that there were no visitors with a positive exposure.

The average total effective dose in 1999 for all monitored DOE/PORTS employees and subcontractors was 0.83 mrem.